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THE HELIOS MECHANICAL DESPIN DRIVE ASSEMBLY FOR THE HIGH-GAIN ANTENNA REFLECTOR

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ABSTRACT

The HELIOS mechanical despin drive assembly for the high-gain antenna reflector is described in this paper. HELIOS is the German-American solar probe which comes within 0.31 Astronomical Units (about 50.10^6 km) of the sun. A special thermal design and a dry lubrication system have resulted in successful operation up to now, with HELIOS having finished its first orbit around the sun.

INTRODUCTION

HELIOS is a German-American solar probe with an elliptical flight path around the sun. HELIOS A was launched on Dec. 10, 1974, and HELIOS B followed in Jan. 1976. Its aphelion is one Astronomical Unit (1 AU) and its perihelion 0.31 AU from the sun. The solar impact to the spacecraft varies between one and eleven solar constants. Figure 1 shows the orbits of earth and HELIOS around the sun. The HELIOS spacecraft is spin-stabilized at 60 rpm and has three antenna systems to achieve ground connection: a low-gain antenna for the near-earth part of the mission before the spacecraft spin axis is oriented orthogonal to the orbit plane; a medium-gain antenna, and a high-gain antenna for the main mission. The high-gain antenna is on the upper side of the spacecraft. It consists of an axial antenna feeder rotating with the spacecraft and a despun reflector, which is also pointed towards the earth. Figure 2 shows the spacecraft's configuration with its high-gain antenna system and the despin drive assembly (DDA). The flight time for one orbit is about six months; three months after launch, HELIOS reaches its closest distance to the sun, which is 46.10^6 km for HELIOS A and 43.10^6 km for HELIOS B. The launch vehicle — a Titan [illegible]enta TE 364-4 combination, the varying thermal environment during the mission, and the ground testing time influenced the design of the reflector [illegible] drive assembly.

The HELIOS Despin Drive Assembly

Figure 3 shows a photograph of the DDA. The design concept of the despin drive assembly had to take into consideration

a) the general HELIOS system aspects
b) the launch conditions
c) the orbit environments

The general HELIOS system aspects — including storage, shipment, and S/C system tests — called for materials which are corrosion-free and for a lubricant which operates in air as well as in vacuum. The launch conditions — acceleration, vibration loads, and acoustic noise — determined the mechanical design and the size of the bearings. The orbit environments — vacuum and an extremely changing thermal impact between one and eleven solar constants — dictated the kind of lubrication system used: dry film lubrication with self-replacement of the film by transfer.

The Mechanical Design of the Despin Drive Assembly

To accommodate the expected load impact during lift-off (14 g at 60 Hz), a three-inch angular contact bearing with 42 balls on each side was chosen. The contact angle varies between 18° and 25°, depending on the axial load impact. The lower bearing, supporting the axial load during the launch phase, is a "fixed" bearing with respect to shaft and housing. The bearing on the other end is preloaded via a preload spring to five pounds. The preload force was optimized during the tests to slightly more than the minimum force necessary to have the balls running in the same track. It was found out during the preselection tests at DFVLR, Munich, how the preload force influences the lifetime of the bearings. Figure 4 shows the DDA configuration, the arrangement of the bearings, and the materials used. The DDA is driven by a brushless DC motor which can overcome a drag torque of 30 oz-in. The nominal drag torque range is from 3.5 oz-in. to 6.4 oz-in. A magnetic pick-up device makes possible the pointing of the reflector towards the earth throughout the mission. The pointing accuracy is specified to be better than 0.7°.

The materials used for the DDA are:

- 440 C stainless steel for the high-precision bearings
- Aluminum for shaft and housing
- Titanium for the bearing seats (similar thermal expansion factor to 440 C)

These materials were chosen because of the wide range of expected temperatures and thermal gradients across shaft and housing.

The goal was not to jam the DDA under all possible flight conditions, which means not closing the radial or axial gap between top bearing and housing. Figure 5 shows the temperatures and thermal gradients necessary to close the radial gap between upper bearing and housing, and Fig. 6 shows the thermal gradient (housing versus shaft) required to close the axial gap. At a shaft temperature of -40°C, a thermal gradient of 20°C could be tolerated (assuming an isothermal housing and an isothermal shaft).

The Lubrication System

The lubrication system chosen is the dry film lubricant "Dry Vac Kote" of Ball Brothers Research Corporation (USA), which is based on molybdenum-disulfide (MoS_2) combined with a phenolic (RULON-A) retainer for relubrication by transfer. The reasons for not using "common" oil or grease lubricants and going to a dry lubrication system are:

a) Expected bearing temperatures from -40 °C to +60 °C
b) Evaporation of oil at high temperatures in vacuum
c) Danger of contamination of spacecraft surfaces.

The Ground Testing of the HELIOS Despin Drive Assembly

HELIOS is the first civilian spacecraft which uses a dry film lubricant for such a mechanical device. Up to now, dry lubricants were used only for instrument size bearings. Because it was not possible to get lifetime data for these lubricants or even design data (e.g., temperature resistance across dry lubricated surfaces or lubricant break-away forces), various tests had to be carried out during the design and development phase of the HELIOS program. In the beginning, a functional support contract was established between the HELIOS project office and the DFVLR Institute for "Flugtreib- und Schmierstoffe" in Munich. The work done at DFVLR can be summarized as follows:

- Literature research
- Preselection tests of bearings, lubricants and separators
- Long-life tests of dry film lubricated bearings in UHV
- Long-life tests of dry film lubricated bearings in thermal vacuum
- HELIOS DDA thermal gradient tests in UHV
- Stand-by for trouble-shooting during the HELIOS mission using a HELIOS DDA in a thermal vacuum chamber which allows independent temperature settings at the shaft and the housing

Details about these tests and the results can be found in Ref. 1. In the following, the HELIOS DDA tests carried out at the subsystem and system levels at the supplier (Ball Brothers) and the HELIOS main contractor (Messerschmitt-Bölkow-Blohm) will be discussed.

HELIOS DDA Lifetime Test in Thermal Vacuum

In the beginning of the program, it was recommended by the HELIOS project office that a thermal vacuum life test be performed in real time on a complete DDA in addition to real-time tests on the DDA bearings. This would more nearly simulate the real environment for the bearings and provide a life test of all other DDA components. To simulate the real environment, a random vibration test (acc. level) was performed before the DDA was put into the thermal vacuum chamber. The lifetime test was done successfully between Apr. '72 and Nov. '73. Figure 7 shows the test history, including the measured torque values at the various temperatures. In order to complete the test in the allotted time, it was decided that the time lost through interruptions could be made up by operating at double speed.

HELIOS DDA Thermal Vacuum Tests

The next DDA system tests were the thermal vacuum tests of the prototype flight units one and two. During the prototype tests, it could be seen that the friction torque went up to 7 oz-in. at shaft temperatures between -40 °C and -50 °C. When the flight units were tested, the friction torque reached 12 oz-in. at the same cold temperatures. Many tests followed, with different bearing separators and different gaps between upper bearing and housing. Finally, it turned out that the drag torque was a function of the torque ripple which occurred due to an end plate (at the lower end of the DDA) misalignment at cold temperatures. During manufacture, the final machining was done with the end plate fixed to the housing. The rotational position of the end plate with respect to the housing was marked, and during the assembly of the DDA, the end plate was screwed on in the same position. During the thermal vacuum tests — especially during the cold phase — it turned out that the above-mentioned fabrication method was not the optimal one. A better way was to fabricate and machine each part by itself with close tolerances and to optimize by test the final position of the end plate on the housing. The resulting drag torque during the cold phase tests was about 5 oz-in. for both flight units.

HELIOS Spacecraft System Solar Simulation Test

The most important test to improve the thermal design of the spacecraft and its components was the HELIOS solar simulation test performed at the Jet Propulsion Laboratory (JPL, California). During this test, the DDA was operated by its motor to simulate flight conditions. The measured temperatures were nearly coincident with the calculated ones for the hot phase at 11 solar constants, but they deviated for the cold phase at 0.9 solar constant. Thermal gradients on the order of -40 °C (shaft warmer than housing) were read out.

This was later explained by a heat leak in the area of the upper flange. As already mentioned, the maximum allowable thermal gradient is -20 °C for the cold phase. Figure 8 shows a summary of the solar simulation test with respect to the behaviour of the DDA. One can see the influence of the temperatures on the friction torque, which influences the motor current and also the pointing accuracy.

The DDA Thermal Gradient Test

This test was necessary to simulate the JPL test and to check the design changes made to obtain warmer temperatures and lower thermal gradients during the cold mission phase. In the first step, the DDA temperatures were set to the JPL measured values. Then the following design changes were made:

a) The heat leak between reflector hub and DDA flange was closed.
b) A heater was added inside the reflector hub to warm up the upper part of the housing and thus to reduce the thermal gradient during the cold phase.

After implementation of these changes, a shaft temperature of -30 °C and a thermal gradient of 8 °C were measured for the cold flight condition.

Flight Data of the HELIOS DDA

Up to now, the performance of the HELIOS DDA has been excellent during the mission. Figures 9 and 10 show the performance of the DDA during the HELIOS A and B missions through March 1976. As can be seen, the measured friction torque (via motor current) is always within the specified values. As a result of the last design changes, the measured temperatures are warmer during aphelion and colder during perihelion.

Conclusion

The flight performance of the dry lubricated HELIOS despin drive assembly for the high-gain antenna reflector shows that the choice of the unusual lubricant was a good one. It confirms a concept which could be used not only for spacecraft but also in extreme earth environments.

References

1. E. Jantzen: A Dry Lubrication System for Spaceproofed Bearings. ESRO Proceedings, 1975.
2. BBRC, Calculation of DDA Endplay, March 1974.
3. MBB, DDA Design Specification.
4. MBB, Test Procedures for DDA.

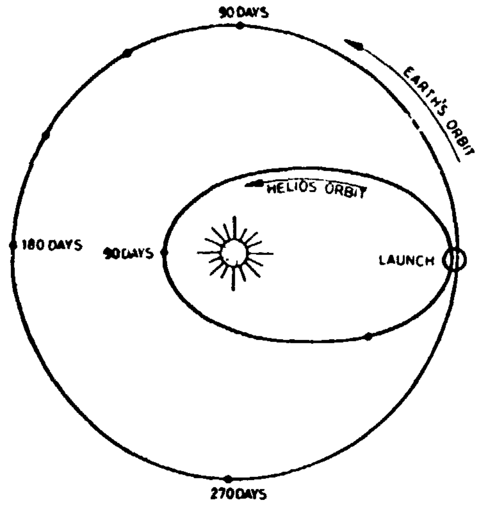

Fig. 1. Orbits of earth and HELIOS around the sun

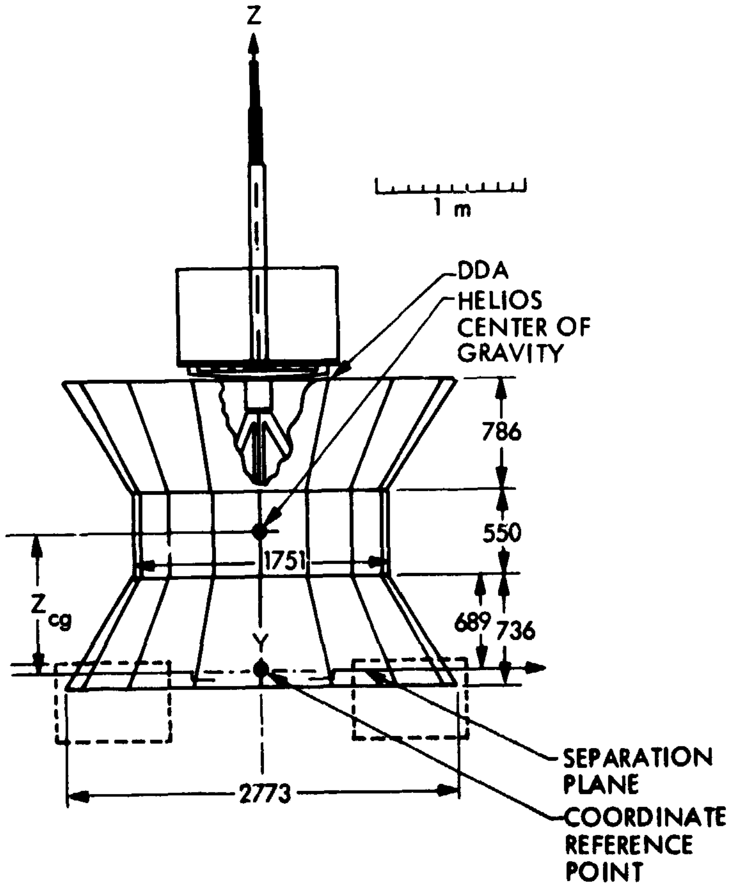

Fig. 2 HELIOS spacecraft dimensions

Fig. 3 The HELIOS despin drive assembly

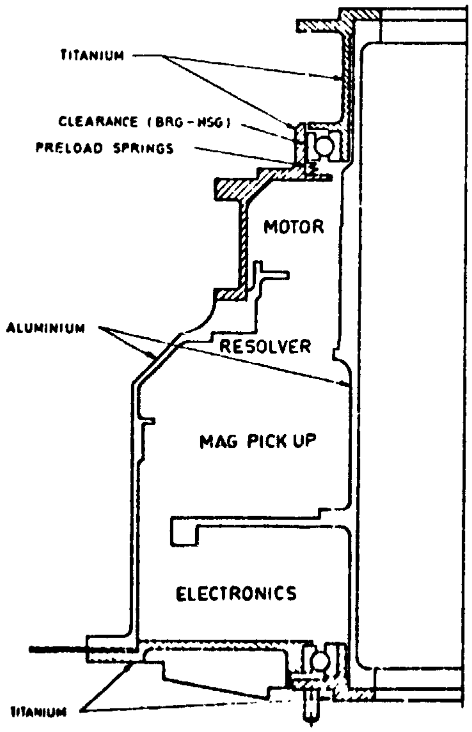

Fig. 4 DDA configuration

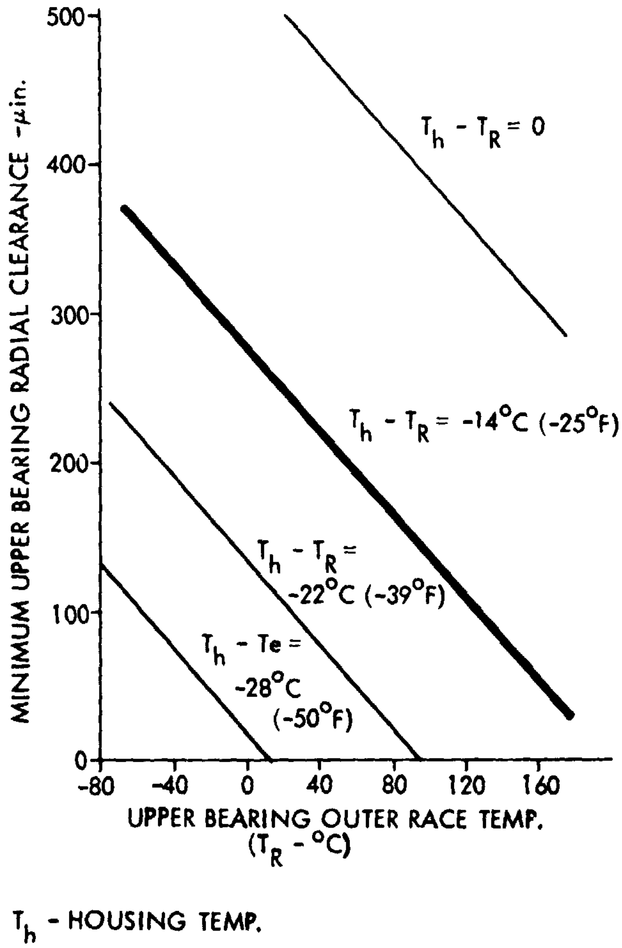

Fig. 5 Thermal gradient required to close upper bearing radial gap

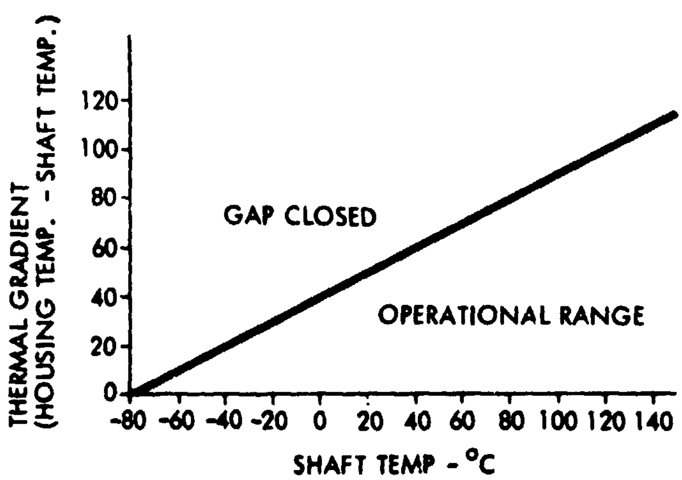

Fig. 6 Thermal gradient (housing vs. shaft) to close an axial gap of 0.0055 inch, assuming an isothermal housing and an isothermal shaft

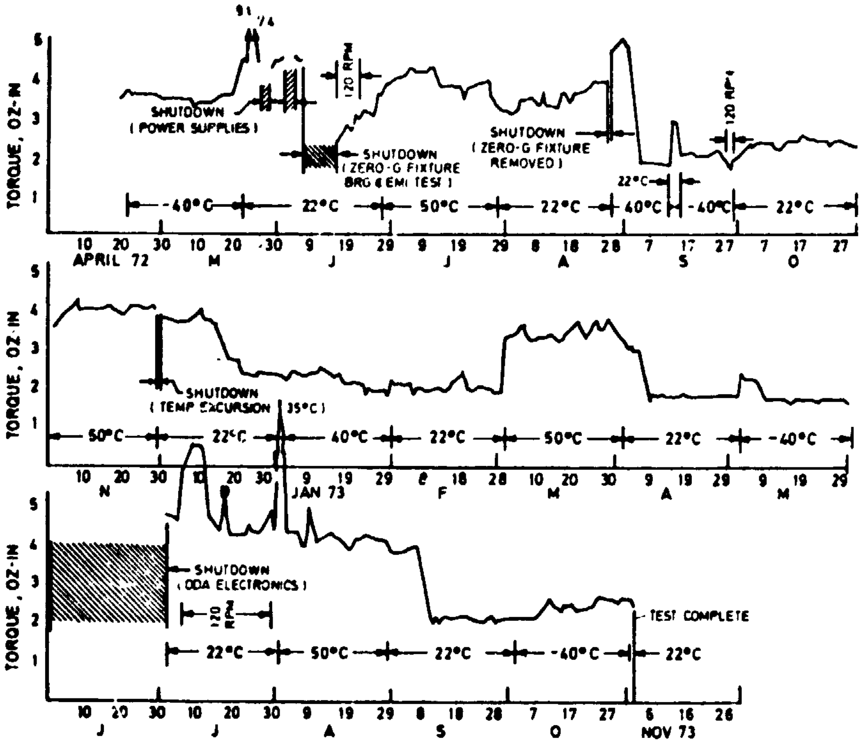

Fig. 7 Summary of DDA T/V life test

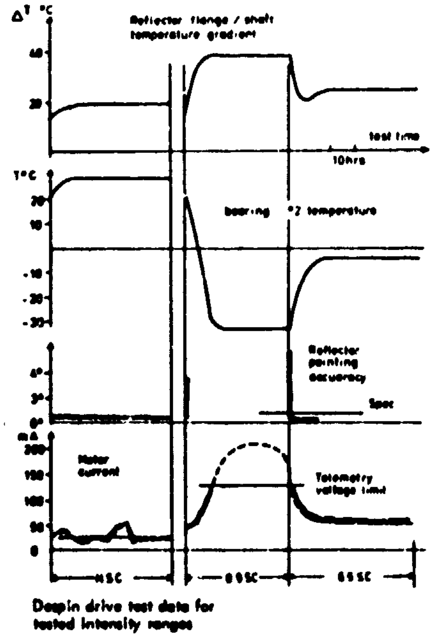

Fig. 8 Summary of HELIOS solar simulation test at JPL (for DDA)

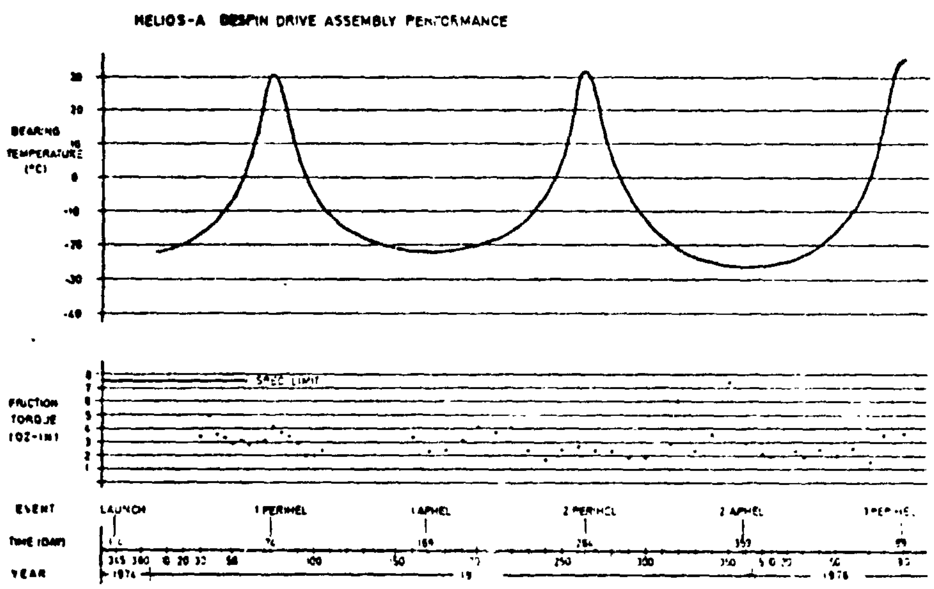

Fig. 9 HELIOS A DDA performance

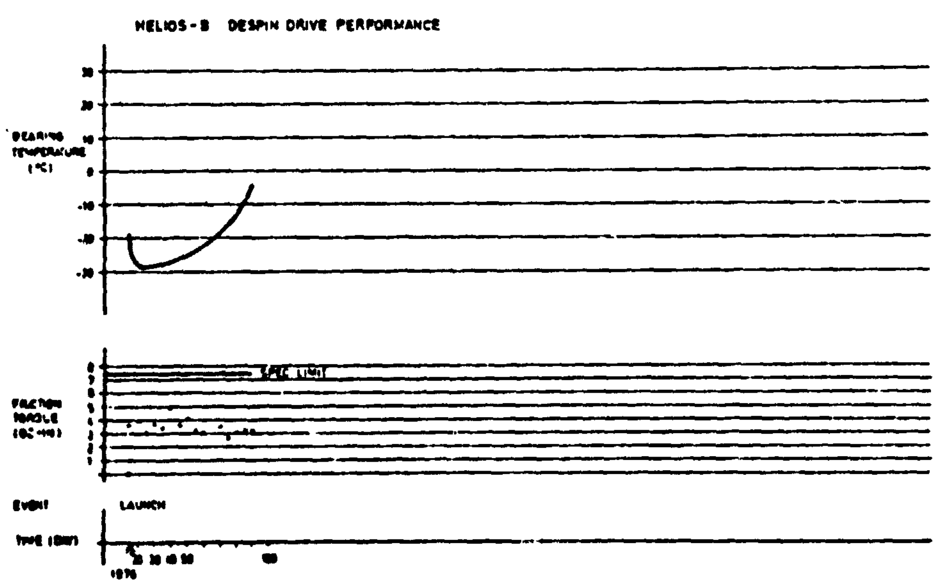

Fig. 10 HELIOS B DDA performance